(19) Europäisches Patentamt / European Patent Office / Office européen des brevets

(11) EP 2 196 072 B9

(12) **CORRECTED EUROPEAN PATENT SPECIFICATION**

(15) Correction information:
Corrected version no 1 (W1 B1)
Corrections, see
Claims EN 1

(48) Corrigendum issued on:
25.01.2012 Bulletin 2012/04

(45) Date of publication and mention of the grant of the patent:
03.08.2011 Bulletin 2011/31

(21) Application number: **09753971.2**

(22) Date of filing: **29.05.2009**

(51) Int Cl.:
H05H 7/10 *(2006.01)* ***H05H 13/00*** *(2006.01)*
G21K 1/14 *(2006.01)*

(86) International application number:
PCT/EP2009/056670

(87) International publication number:
WO 2009/144316 (03.12.2009 Gazette 2009/49)

(54) A STRIPPING MEMBER, A STRIPPING ASSEMBLY AND A METHOD FOR EXTRACTING A PARTICLE BEAM FROM A CYCLOTRON

ABSTREIFELEMENT, ABSTREIFANORDNUNG UND VERFAHREN ZUR EXTRAKTION EINES PARTIKELSTRAHLS AUS EINEM ZYKLOTRON

ÉLÉMENT DE STRIPPING, ENSEMBLE DE STRIPPING ET PROCÉDÉ PERMETTANT D'EXTRAIRE UN FAISCEAU DE PARTICULES D'UN CYCLOTRON

(84) Designated Contracting States:
AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO SE SI SK TR

(30) Priority: **30.05.2008 EP 08157373**

(43) Date of publication of application:
16.06.2010 Bulletin 2010/24

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Printed by Jouve, 75001 PARIS (FR)

Description

TECHNICAL FIELD

[0001] The present invention relates to the field of charged particle accelerators, such as a cyclotron. More particularly, the present invention relates to a stripping member, a stripping assembly as well as a method for extracting a particle beam from a cyclotron.

DESCRIPTION OF RELATED ART

[0002] Cyclotrons are largely used in many applications such as medical applications (e.g. production of radioisotopes or particle therapy), scientific research and industrial applications.

[0003] A cyclotron is a re-circulation particle accelerator that works under high vacuum and accelerates ions up to energies of a few MeV, and even more. Charged particles, which have been previously generated by an ion source, are accelerated in a spiral motion within the cyclotron and are, at the end of said spiral motion, extracted from the cyclotron by means of an extraction system.

[0004] Particles acceleration within a cyclotron is achieved by using on the one hand a magnetic field, generated by an electromagnet, which causes the particles, coming from the ion source, to follow a circular path in a plane perpendicular to said magnetic field, and on the other hand by means of an electric field generated by a RF system (comprising a high frequency power supply) capable of applying a high-frequency alternating voltage which increasingly accelerates particles.

[0005] As a result, particles follow a spiral path by gaining energy (increase of energy implies an increase of particles orbit radius) until the outer radius of the cyclotron where they can either be extracted out of the cyclotron, or, in specific applications, used inside the cyclotron itself, for example for producing isotopes. However, in most of applications it is required to extract the ion beam out of the cyclotron, and guide it to a target where it can be used. In this case an extraction system is typically installed near the internal outer radius of the cyclotron.

[0006] For extracting positively charged particles the common extraction method is achieved by means of an electrostatic deflector which produces a strong electric field capable of deflecting accelerated particles from its acceleration orbit into an extraction orbit. This electrostatic deflector typically consists of a very thin electrode called septum which is placed between the last internal orbit of the cyclotron and the extraction orbit through which particles will be extracted. However, this extraction method has two main drawbacks, as follows. The first drawback is that the extraction efficiency of such a method is quite limited, thereby limiting the maximum beam intensity that can be extracted due to thermal heating of the septum by the intercepted beam. The second drawback is that interception of particles by the septum contributes strongly to the radio-activation of the cyclotron.

[0007] Another extraction method is known from EP0853867 (by the Applicant), wherein the ion beam can be extracted from the cyclotron without the use of any extraction system. However, the main drawback of this technique consists in that said method is complex.

[0008] Another common extraction method is the stripping extraction method which uses a carbon stripping foil in order to extract a negative ion beam coming from a negative ion source which is converted into a positive ion beam by stripping one or more of the electrons of the negative ion. The extraction efficiency of such a method can be as high as 99% and is much simpler than the previous ones and depends on the material thickness. The bigger thickness of a stripping material the more the ion beam is enlarged. As a consequence, the dispersion of the beam exiting the cyclotron increases when the thickness of the stripping foil increases.

[0009] Typically, carbon stripping foils are mounted on stripping probes or forks and are inserted inside the vacuum chamber of the cyclotron by means of a stripper arm in the outer region of the cyclotron (this insertion is well known in the art). Stripping foils are usually made up of carbon and have a size of the order of 2 x 2 cm. The high intensity negative ion beam (such as H- or D^-) is accelerated inside the accelerator along a spiral path and then it is scattered by such a stripping foil. During the hit between said negative ion beam and the surface of said stripper foil, two electrons of the negative ion beam are stripped away by the stripping foil, due to the Coulomb force between the atomic nucleus of the substance of said stripping foil and the negative ion beam. As a result, desired charged particles are obtained, such as protons for example, while the two stripped electrons are used to measure the current of the negative ion beam by means of grounded acquisition electronics.

[0010] Since in a cyclotron this interaction takes place in the magnetic field which provides the rotational component of the accelerating orbit, the change of the specific charge of the ion results in the change of direction of the ion orbit after the stripper foil. This particular effect is typically used for extracting an ion beam from a cyclotron, as represented in **Fig.1**, wherein the negative ion H- orbit, before the stripper foil 100, is represented by a solid line, while the positive ion H^+ orbit, after the stripper foil 100, is represented by a dashed line and where B represents the magnetic field direction perpendicular to the ion beam orbit. The two stripped electrons 2e are used for measuring the current of the ion beam by means of grounded acquisition electronics 101.

[0011] **Fig.2** similarly shows the extraction process of the negative ion beam 1000 in the extraction region of a cyclotron wherein a stripper foil 100 is provided. The negative ion beam after passing through the stripper foil 100 changes its orbit radius and consequently exits the cyclotron.

[0012] In many applications, the energy of the ion beam generated by a cyclotron may not be fixed. In fact, the production of several ion beams with different energy (i.e. with different radius orbits) is typically required and, in this case, each of the desired ion beams has a corresponding foil position within the extraction region in order to extract the ion beam out of the cyclotron.

[0013] However, conventional stripping foils are very fragile due to extraction efficiency requirements and, consequently, are not capable of maintaining their physical properties during repeated ion hits. Such repeated hits typically cause in fact excessive heating and, consequently, damages of stripper foils. Moreover, when the vacuum condition of the accelerator is lost (during standard maintenance procedures or during the event of a sudden accidental vacuum loss, for example) the stripper foil typically cracks due to pressure variations. As a consequence, the lifetime of conventional stripper foils is very short, and typical lifetime ranges are from a few hours to a few days, depending on the beam current intensity and density.

[0014] As already mentioned, the choice of stripper foil thickness and, consequently, the stripper foil lifetime depend on the energy of the ion beam and also on the type of ion beam to be extracted. It is well known in the art that stripping foils having thickness between 2 μm and 5 μm have very high extraction efficiency but a very low durability (due to mechanical stress and/or heating due to repeated ion hits). By contrast, stripping foils with thickness between 16 μm and 50 μm have a very high durability but at the same time lower extraction efficiency which may be between for example between 50% and 65%.

[0015] The extraction efficiency depends therefore on the thickness of the stripping foil as follows. When the negative ion beam passes through the stripper foil, there are beam losses due to mechanism of multiple scattering. Multiple scattering consists in the increase of the beam emittance, i.e. the dispersal of the particle beam into a range of directions, when the beam passes through the stripper foil as a result of collisions between the particle beam and the stripper foil. The higher the thickness of the stripper foil, the more multiple scattering increases. Since the exit of the cyclotron has a very small diameter, if the emittance of the stripped particle beam is higher, a larger fraction of the particle beam may be lost because unable to pass through the exit of the cyclotron.

[0016] As mentioned before, conventional stripping foils are fragile and due to wear need to be replaced regularly. Replacing a stripper foil is cumbersome and takes time: the vacuum inside the cyclotron is broken, the cyclotron is opened, human doses in maintenance must be taken, the stripper foil is replaced, the cyclotron is closed, and the cyclotron is pumped down until good vacuum is obtained. To overcome this problem, Heikkinen et al. (Cyclotron development program at Jyvaskyla, Cylotron and their applications 2001, Sixteenth International Conference) have installed a stripper mechanism with a rotating foil holder having four stripper foils, in a vacuum tank of a 30MeV cyclotron. In case a stripper foil is damaged, the stripper mechanism is rotated in order to position a new stripper foil in front of the beam. However, this mechanism is too cumbersome for smaller cyclotrons like 18 MeV cyclotrons. Moreover, in case of failure of a stripping foil, if the beam is not stopped, it hits and damages the vacuum chamber or other structures inside of the cyclotron. To avoid this, a probe is located inside the cyclotron to detect a failure and provide the information to stop the beam. Then the wheel is rotated to position a new stripping foil in the trajectory of the beam and the beam acceleration is restarted. In addition, the implementing of a probe for detecting a failure complicates the device and causes an additional bulk inside the cyclotron. Such a probe in combination with such a rotating foil holder is not implementable in the reduced volume available inside a smaller cyclotron. Another drawback of this solution brought by these authors is that even if the cyclotron is not opened, in the case of production of short half-life radioisotopes, it is important to minimize the time of replacing of the stripper foil and to avoid the stopping of the beam.

[0017] It is an object of the present invention to provide a new kind of stripping assembly and stripping member, as well as a method which overcome the drawbacks of the prior art.

[0018] It is another object of the present invention to provide a stripping assembly and a stripping member, as well as a method which provide high extraction efficiency and high durability with respect to conventional stripper foils during repeated ion hits and even when vacuum condition of the cyclotron is lost.

[0019] It is still another object of the present invention to provide a stripping assembly and a stripping member, as well as a method which on the one hand improves the throughput of the cyclotron and on the other hand minimizes maintenance procedures time.

SUMMARY OF THE INVENTION

[0020] The invention is related to a stripping member and methods as described in the appended claims. Specific embodiments are described in combinations of the independent claims with one or more of the dependent claims. According to a first aspect of the present invention, a stripping member for stripping electrons off a negatively charged particle beam at the periphery of a cyclotron, and for extracting a particle beam out of said cyclotron is provided. Said stripping member comprises a first stripper foil adapted for being located at the periphery of said cyclotron so that said particle beam passes through said first stripper foil and it further comprises a second stripper foil adapted for being located at the periphery of said cyclotron at a more peripheral radius than said first stripper foil and arranged in a common plane and in a side-by-side relationship with the first stripper foil, so that when said first stripper foil is damaged, said negatively charged particle beam passes through said second stripper foil. The stripper foils are arranged in such a way that the changeover from the first to the second foil in case of damage to the first foil takes place without the need to stop the beam and without the need to move the stripping member.

[0021] Advantageously, the thickness of said second stripper foil is higher than the thickness of said first stripper foil.

[0022] Preferably, said first stripper foil and said second stripper foil are both made of pyrolytic carbon.

[0023] More advantageously, said first stripper foil has a grammage comprised between 2 $\mu g/cm^2$ and 10 *g/cm^2 and said second stripper foil has a grammage comprised between 12 $\mu g/cm^2$ and 35 $\mu g/cm^2$.

[0024] According to a second aspect of the present invention, a stripping assembly for stripping electrons off a negatively charged particle beam at the periphery of a cyclotron for extracting a particle beam out of said cyclotron is provided. Said stripping assembly comprises the stripping member according to the first aspect of the invention as well as support means adapted to maintain said stripping member at the periphery of said cyclotron.

[0025] Advantageously, the stripping assembly further comprises adjusting means capable of adjusting the position of said stripping member within the cyclotron whereby increasing the extraction efficiency of said stripping member when said negatively charged particle beam is being stripped by said second stripper foil.

[0026] Preferably, according to said second aspect, said support means is adapted to support a second stripping member of the same type having a third stripper foil and a fourth stripper foil.

[0027] More preferably, said stripping assembly further comprises driving means adapted to move said support means from a first position wherein said negatively charged particle beam is stripped either by first stripper foil or second stripper foil of said first stripping member, to a subsequent second position wherein said negatively charged particle beam is stripped either by said third stripper foil or said fourth stripper foil of said second stripping member. According to an embodiment, said support means is a rotatable stripper head, rotatable around a vertical axis, perpendicular to the particle beam path.

[0028] According to a third aspect of the present invention, a method for stripping electrons off a negatively charged particle beam at the periphery of a cyclotron for extracting a particle beam out of said cyclotron is provided. This method comprises the following steps:

- providing the stripping member according to the first aspect of the invention;
- extracting said particle beam by means of the first stripper foil;
- without stopping said charged particle accelerator, in case said first stripper foil is damaged, extracting said particle beam by means of said second stripper foil.

[0029] Preferably, said step of extracting said charged particle beam by means of the second stripper foil further comprises the step of:

- adjusting by means of adjusting means the positioning of said stripping member inside said charged particle accelerator so as to increase the extraction efficiency of said second stripper foil.

[0030] More preferably, said method comprises the steps of:

- providing a second stripping member of the same type having a third stripper foil and a fourth stripper foil;
- providing support means for supporting said second stripping member and said first stripping member;
- checking if said first stripper foil or said second stripper foil of said first stripping member is damaged;
- when said check reveals damages, moving said support means in such a way that said charged particle beam is stripped either by said third stripper foil or said fourth stripper foil of said second stripping member

BRIEF DESCRIPTION OF THE DRAWINGS

[0031] **Fig. 1** show the interaction between a negative ion and a stripper foil. After this interaction, the negative ion becomes positive and consequently the orbit is modified.

[0032] **Fig. 2** shows a top view of a section of the extraction region of a cyclotron.

[0033] **Fig. 3** and **Fig. 4** show views of the stripping member when stripping the negative ion beam, according to a first aspect of the present invention.

[0034] **Fig. 5** is a view of a stripping assembly according to a first embodiment of a second aspect of the present invention.

[0035] **Fig. 6** is a perspective side view of a stripping assembly according to a second embodiment of the second aspect of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

[0036] According to a first aspect of the present invention, as schematically represented in **Fig. 3,** a stripping member 2 is provided. Said stripping member 2 comprises a first stripper foil 10 and a second stripper foil 20 which are sandwiched on both sides by means of a metallic fork 30 comprising two metallic frames tightened together by screws 4. Said metallic fork 30 maintains said first stripper foil 10 and said second stripper foil 20 arranged in parallel in a common plane and in a side-by-side relationship. This includes adjacent foils with edges in contact with each other, foils with overlapping edges and foils with a narrow open space in between. No solid material such as metal is present however between the adjacent foils.

[0037] Said first stripper foil 10 is located at the distal region of the stripping member 2 while the second stripper foil 20 is located at the proximal region of the stripping member 2, in such a manner that when the stripping member 2 is inserted inside the cyclotron, first stripper foil 10 and second stripper foil 20 are respectively located in a more inwards position and in a more outwards position within the internal region of the cyclotron (the terms distal/proximal and inwards/outwards being with respect to the cyclotron's central axis). As a consequence, the negative ion beam 1000, during its spiral path, will reach at first the first stripper foil 10, as described below.

[0038] In other embodiments of the present invention, the two stripper foils 10, 20 may be supported by different forks and located at different radii in the cyclotron, whilst still being positioned side-by-side in a common plane. For example, two forks as shown in figure 3 may be positioned with the fork openings facing each other, each fork containing one foil.

[0039] Stripping foils 10, 20 are both made up of a pyrolytic carbon material which is a carbon material similar to graphite which is typically obtained by depositing gaseous hydrocarbon compounds on suitable underlying substrates (carbon materials, metals, ceramics) at temperatures ranging from 1000 to 2500 K (chemical vapour deposition). Pyrolytic carbon has a better durability and resistance with respect to conventional carbon used for manufacturing stripper foils.

[0040] According to an embodiment of the present invention, stripper foils 10, 20 have different thickness. A foil may be characterized by its thickness, expressed in μm or characterized by its grammage, like in paper industry, that is the mass per area of foil expressed here in $\mu g/cm^2$. The thickness of the foil in μm is obtained by dividing the grammage by the density of the foil material. For example, first stripper foil 10 has a thickness of 5 μm and presents, as noticed by the Applicant, an extraction efficiency of about 90%, while second stripper foil 20 has a thickness of 25 μm and presents an extraction efficiency of about 75%. As a consequence, second stripper foil 20 is more resistant to damages with respect to first stripper foil 10 but has lower extraction efficiency.

[0041] According to the invention, the second stripper foil 20 is used only when the first stripper foil 10 is damaged and acts, therefore, as a backup stripper foil. When in use, the stripping member 2 is positioned in a nominal position which is slightly inwards the outer internal region of the cyclotron (not shown), as well known in the art. After the high intensity negative ion beam 1000 has travelled its spiral path by gaining energy, it intercepts the first stripper foil 10 of the stripping member 2 and it is finally extracted by said first stripper foil 10. When said first stripper foil 10 should be damaged (caused for example by repeated hits, standard machine openings, or vacuum loss or heating, as previously described) as shown in **Fig.4,** it is still possible to strip the negative ion beam 1000 by means of the second stripper foil 20. In fact, when first stripper foil 10 breaks, the negative ion beam 1000 is no more extracted and keeps turning inside the cyclotron until it reaches (after a certain number of further turns) the second stripper foil 20 of the stripping member 1, the latter which acts as a backup stripper foil. The change from the first foil to the second takes place automatically, i.e. without any outside interception, without the need to stop the beam and without movement of the stripping member with respect to the beam. In this manner, therefore, it is no more necessary to stop and open the cyclotron for replacing the damaged stripper foil with a new one. As a consequence the throughput of the cyclotron can be highly improved with respect to prior art. The use of a thin first stripper foil 10 allows the cyclotron to have very high extraction efficiency, but the foil is also more fragile and will break more easily. It is advantageous in that case to have a second stripper foil which is thicker.

[0042] According to a second aspect of the present invention, a stripping assembly 1, as schematically shown in **Fig. 5,** is provided. The stripping assembly 1, according to a first embodiment, comprises a support means, such as a stripper arm 40, for maintaining said stripping member 2, within the cyclotron, in the outer internal region thereof.

[0043] Adjusting means (not shown) for adjusting the position of the stripping assembly 1 and therefore the position of said second stripper foil 20 with respect to the incoming negative ion beam 1000 within the cyclotron may be further provided in order to decrease the dispersion of the stripped particle beam over the exit of the cyclotron and therefore increase the extraction efficiency of the second stripper foil 20. The adjusted position may be any position, linear or angular, e.g. linear along a radial direction with respect to the central axis, or angular around said central axis or around a horizontal axis.

[0044] According to a second embodiment of the second aspect of the present invention, said stripping assembly 1 comprises, instead of the stripper arm 40, a stripper head 41 capable of supporting an additional second stripping member 3, the latter comprising a third stripper foil 11 and a fourth stripper foil 21, maintained by means of a second fork 31, as represented by **Fig. 6**. Said stripper head 41 is capable of rotating by means of driving means (not shown) around a vertical axis A perpendicular to the negative ion beam 1000.

[0045] Third stripper foil 11 and fourth stripper foil 21 of second stripping member 3 have the same characteristics as first stripper foil 10 and second stripper foil 20 of stripping member 2 respectively. According to this second embodiment, it is possible to rotate the stripping assembly 1 so as to intercept the negative ion beam 1000 either with stripper foils 10, 20 of stripping member 2 or with stripper foils 11, 21 of second stripping member 3. As shown in **Fig.6** the negative ion beam 1000 is being stripped by the stripper foil 21 of second stripping member 3, after rotating the stripper head 41 over a predefined angle θ around the axis A.

[0046] According to a third aspect of the present invention, a method for stripping said negative ion beam 1000 coming from a charged particle accelerator is provided. By following the steps of such a method it is possible to easily and quickly replace a damaged stripper foil with a second one without stopping and opening the cyclotron. In fact, when the first stripper foil 10 has been damaged, as already described, the negative ion beam 1000 is no more extracted and keeps turning until it reaches the second stripper foil 20 of said stripper member 2. The second stripper foil 20 consequently acts as a back-up foil.

[0047] According to a variant of said third aspect of the present invention, it is also possible to rotate the stripping assembly 1 of figure 6 over a certain predefined angle θ in such a way that the negative ion beam 1000 is consequently stripped by one of the stripper foils 11, 21 of the second stripping member 3, while the stripping member 2 with damaged stripper foils 10, 20 can be easily put aside from the trajectory of the negative ion beam 1000. However, it is clear that depending on the application one can decide which stripper foil of which stripping member is to be used. Therefore, the order in which one uses the stripper foils can be easily modified without departing from the invention. Using the embodiment of figure 6, it is possible to rotate the holder over θ while the beam remains active, so that foils 11 and 21 act as back-up foils. However, the preferred way of operating is by choosing the thicknesses of the foils 10 and 20 in relation to a particular treatment, so that it is substantially certain that the back-up foil 20 does not break during beam-operation. After the treatment, it is then possible to rotate the holder so that an additional treatment can be given, using foils 11 and 21. In this way, the vacuum remains unbroken between foil replacements.

[0048] One or more embodiments of the present invention have been described in detail with reference to the attached figures. It is evident that the invention is only limited by the claims, since the figures described are only schematic and therefore non-limiting. In the figures, the size of some of the elements may be exaggerated and not drawn on scale for illustrative purposes. The dimensions and the relative dimensions do not necessarily correspond to actual reductions to practice of the invention. Further, those skilled in the art can recognize numerous variations and modifications of this invention that are encompassed by its scope. Accordingly, the description of preferred embodiments should not be deemed to limit the scope of the present invention.

Claims

1. A stripping member (2) for stripping electrons off a negatively charged particle beam (1000) at the periphery of a cyclotron for extracting a particle beam out of said cyclotron, said stripping member (2) comprising a first stripper foil (10) adapted for being located at the periphery of said cyclotron so that said negatively charged particle beam (1000) passes through said first stripper foil (10), said stripping member comprises a second stripper foil (20) adapted for being located at the periphery of said cyclotron at a more peripheral radius than said first stripper foil (10) and arranged in a common plane with the first stripper foil (10) **characterized in that** said second stripper foil is in a side-by-side relationship with said first stripper foil, so that when the first stripper foil is damaged, said negatively charged particle beam (1000) passes through said second stripper foil (20).

2. The stripping member (2) according to claim 1 wherein the thickness of said second stripper foil (20) is higher than the thickness of said first stripper foil (10).

3. The stripping member (2) according to claim 1 or claim 2 wherein said first stripper foil (10) and said second stripper foil (20) are both made of pyrolytic carbon.

4. The stripping member (2) according to any of previous claims wherein said first stripper foil (10) has a grammage comprised between 2 $\mu g/cm^2$ and 10 $\mu g/cm^2$ and said second stripper foil (20) has a grammage comprised between 12 $\mu g/cm^2$ and 35 $\mu g/cm^2$.

5. A stripping assembly (1) for stripping electrons off a negatively charged particle beam (1000) at the periphery of a cyclotron, for extracting a particle beam out of said cyclotron, said stripping assembly (1) being **characterized in that** it comprises:

- the stripping member (2) according to any of claims 1 to 4;
- support means (40, 41) adapted to maintain said stripping member (2) at the periphery of said cyclotron.

6. The stripping assembly (1) according to claim 5, comprising adjusting means capable of adjusting the position of said stripping member (2) within the cyclotron, thereby increasing the extraction efficiency of said stripping member (2) when said negatively charged particle beam 1000 is being stripped by said second stripper foil (20).

7. The stripping assembly (1) according to claim 5 or claim 6 wherein said support means (41) are adapted to support said first (2) and a second stripping member (3) of the same type as the first stripping member (2), the second stripping member (3) having a third stripper foil (11) and a fourth stripper foil (21).

8. The stripping assembly (1) according to claim 7 comprising driving means adapted to move said support means (41) from a first position wherein said negatively charged particle beam (1000) is stripped either by said first stripper foil (10) or said second stripper foil (20) of said first stripping member (2), to a subsequent second position wherein said negatively charged particle beam (1000) is stripped either by said third stripper foil (11) or said fourth stripper foil (21) of said second stripping member (3).

9. The stripping assembly (1) according to claim 7 or 8 wherein said support means (41) is a rotatable stripper head, rotatable around a vertical axis, perpendicular to the particle beam path.

10. A method for stripping electrons off a negatively charged particle beam (1000) at the periphery of a cyclotron for extracting a particle beam out of said cyclotron, the method **characterized in that** it comprises the following steps:

- providing the stripping member (2) of any of claims 1 to 4 in the periphery of said cyclotron;
- extracting said particle beam by means of the first stripper foil (10);
- without stopping said cyclotron, in case said first stripper foil (10) is damaged, extracting said particle beam by means of said second stripper foil (20).

11. The method according to claim 10 wherein said step of extracting said particle beam by means of the second stripper foil (20) further comprises the step of :

- adjusting by means of adjusting means the positioning of said stripping member (2) inside said cyclotron so as to increase the extraction efficiency of said second stripper foil (20).

12. The method according to claim 10 or claim 11 further comprising the steps of :

- providing a second stripping member (3) of the same type of said first stripping member (2), having a third stripper foil (11) and a fourth stripper foil (21);
- providing support means (41) for supporting said second stripping member (3) and said first stripping member (2);
- checking if said first stripper foil (10) or said second stripper foil (20) of said first stripping member (2) is damaged;
- when said check reveals damages, moving said support means (41) in such a way that said negatively charged particle beam (1000) is stripped either by said third stripper foil (11) or said fourth stripper foil (21) of said second stripping member (3).

Patentansprüche

1. Ein Stripperelement (2) zum Abstreifen von Elektronen aus einem negativ geladenen Teilchenstrahl (1000) am Umfang eines Zyklotrons zum Extrahieren eines Teilchenstrahls aus dem Zyklotron, wobei das Stripperelement (2) eine erste Stripperfolie (10), die zum Anordnen am Umfang des Zyklotrons derart geeignet ist, dass der negative geladene Teilchenstrahl (1000) die erste Stripperfolie (10) durchdringt, sowie eine zweite Stripperfolie (20), die zum Anordnen am Umfang des Zyklotrons in einem Umfang mit größerem Radius als die erste Stripperfolie (10) geeignet und in der gleichen Ebene wie die erste Stripperfolie (10) angeordnet ist, umfasst und **dadurch gekennzeichnet ist, dass** die zweite Stripperfolie (20) seitlich der ersten Stripperfolie (10) angeordnet ist, so dass im Fall einer Beschädigung der ersten Stripperfolie der negativ geladene Teilchenstrom (1000) die zweite Stripperfolie (20) durchdringt.

2. Das Stripperelement (2) nach Anspruch 1 **gekennzeichnet dadurch, dass** die Dicke der zweiten Stripperfolie (20) größer als die Dicke der ersten Stripperfolie (10) ist.

3. Das Stripperelement (2) nach einem der Ansprüche 1 oder 2 **gekennzeichnet dadurch, dass** sowohl die erste Stripperfolie (10) als auch die zweite Stripperfolie (20) aus Pyrocarbon bestehen.

4. Das Stripperelement (2) nach einem der vorhergehenden Ansprüche **gekennzeichnet dadurch, dass** das Flächengewicht der ersten Stripperfolie (10) zwischen 2 $\mu g/cm^2$ und 10 $\mu g/cm^2$ und dasjenige der zweiten Stripperfolie (20) zwischen 12 $\mu g/cm^2$ und 35 $\mu g/cm^2$ beträgt.

5. Eine Strippingvorrichtung (1) zum Abstreifen von Elektronen aus einem negativ geladenen Teilchenstrahl (1000) am Umfang eines Zyklotrons zum Extrahieren eines Teilchenstrahls aus dem Zyklotron, wobei die Strippingvorrichtung (1) **dadurch gekennzeichnet ist, dass** sie

- das Stripperelement (2) nach einem der Ansprüche 1 bis 4 sowie
- Haltevorrichtungen (40, 41), die zum Fixieren des Stripperelements (2) am Umfang des Zyklotrons geeignet ist, beinhaltet.

6. Die Strippingvorrichtung (1) nach Anspruch 5, die Mittel zum Einstellen umfasst, mit welchen die Postion des Stripperelements (2) innerhalb des Zyklotrons justiert werden kann, wodurch der Extraktionskoeffizient des Stripperelements (2) beim Abstreifen aus dem negativ geladenen Teilchenstrahl (1000) durch die zweite Stripperfolie (20) erhöht wird.

7. Die Strippingvorrichtung (1) nach Anspruch 5 oder 6 bei welcher die Haltevorrichtungen (41) geeignet sind, das erste (2) und das zweite Stripperelement (3), das von gleicher Bauart wie das erste Stripperelement (2) ist, zu halten, wobei das zweite Stripperelement (3) eine dritte Stripperfolie (11) und eine vierte Stripperfolie (21) aufweist.

8. Die Strippingvorrichtung (1) nach Anspruch 7 umfassend Antriebsmittel zum Bewegen der Haltevorrichtungen (41) aus einer ersten Stellung, in welcher das Abstreifen aus dem negativ geladenen Teilchenstrahl (1000) entweder durch die erste Stripperfolie (10) oder die zweite Stripperfolie (20) des ersten Stripperelements (2) erfolgt, in eine folgende zweite Stellung, in welcher das Abstreifen aus dem negativ geladenen Teilchenstrahl (1000) entweder durch die dritte Stripperfolie (11) oder die vierte Stripperfolie (21) des zweiten Stripperelements (3) erfolgt.

9. Die Strippingvorrichtung (1) nach Anspruch 7 oder 8, wobei es sich bei den Haltevorrichtungen (41) um einen um eine vertikale Achse drehbaren und senkrecht zur Bahn des Teilchenstrahls angeordneten Stripperkopf handelt.

10. Ein Verfahren zum Abstreifen von Elektronen aus einem negativ geladenen Teilchenstrahl (1000) am Umfang eines Zyklotrons zum Extrahieren eines Teilchenstrahls aus dem Zyklotron, wobei das Verfahren durch die folgenden Schritte **gekennzeichnet** ist:

- Vorsehen eines Stripperelements (2) nach einem der Ansprüche 1 bis 4 am Umfang des Zyklotrons,
- Extrahieren des Teilchenstrahls mittels der ersten Stripperfolie (10) und
- Extrahieren des Teilchenstrahls mittels der zweiten Stripperfolie (20) ohne Betriebsunterbrechung des Zyklotrons, falls die erste Stripperfolie (10) eine Beschädigung erleidet.

11. Das Verfahren nach Anspruch 10, wobei der Schritt des Extrahierens des Teilchenstrahls mittels der zweiten Stripperfolie (20) weiterhin den Schritt des Justierens der Position des Stripperelements (2) innerhalb des Zyklotrons mit Hilfe von Mitteln zum Einstellen derart, dass die Extraktionswirkung der zweiten Stripperfolie (20) erhöht wird, umfasst.

12. Das Verfahren nach Anspruch 10 oder 11, das weiterhin die Schritte

- Vorsehen eines zweiten Stripperelements (3) von der gleichen Art wie das erste Stripperelement (2) und beinhaltend eine dritte Stripperfolie (11) und eine vierte Stripperfolie (21),
- Vorsehen von Haltevorrichtungen (41) für das zweite Stripperelement (3) und das erste Stripperelement (2),
- Prüfen der ersten Stripperfolie (10) oder der zweiten Stripperfolie (20) am ersten Stripperelement (2) auf Beschädigung sowie
- im Fall einer Beschädigung Bewegen der Haltevorrichtungen (41) in der Weise, dass Abstreifen aus dem negativ geladenen Teilchenstrahl (1000) entweder durch die dritte Stripperfolie (11) oder die vierte Stripperfolie (21) des zweiten Stripperelements (3) erfolgt,

umfasst.

Revendications

1. Élément de stripping (2) pour arracher des électrons d'un faisceau de particules négativement chargées (1000) à la périphérie d'un cyclotron pour extraire un faisceau de particules dudit cyclotron, ledit élément de stripping (2) comprenant une première feuille de stripping (10) adaptée pour être située à la périphérie dudit cyclotron de sorte que ledit faisceau de particules négativement chargées (1000) traverse ladite première feuille de stripping (10), ledit élément de stripping comprend une deuxième feuille de stripping (20) adaptée pour être située à la périphérie dudit cyclotron à un rayon plus périphérique que ladite première feuille de stripping (10) et agencée dans un plan commun avec la première feuille de stripping (10), **caractérisé en ce que** ladite deuxième feuille de stripping est située côte à côte avec ladite première feuille de stripping, de sorte que lorsque ladite première feuille de stripping est endommagée, ledit faisceau de particules négativement chargées (1000) traverse ladite deuxième feuille de stripping (20).

2. Élément de stripping (2) selon la revendication 1 dans lequel l'épaisseur de ladite deuxième feuille de stripping (20) est supérieure à l'épaisseur de ladite première feuille de stripping (10).

3. Élément de stripping (2) selon la revendication 1 ou la revendication 2 dans lequel ladite première feuille de stripping (10) et ladite deuxième feuille de stripping (20) sont toutes deux constituées de carbone pyrolytique.

4. Élément de stripping (2) selon l'une quelconque des revendications précédentes dans lequel ladite première feuille de stripping (10) a un grammage compris entre 2 $\mu g/cm^2$ et 10 $\mu g/cm^2$ et ladite deuxième feuille de stripping (20) a un grammagecompris entre 12 $\mu g/cm^2$ et 35 $\mu g/cm^2$.

5. Ensemble de stripping (1) pour arracher des électrons d'un faisceau de particules négativement chargées (1000) à la périphérie d'un cyclotron pour extraire un faisceau de particules dudit cyclotron, ledit ensemble de stripping (1) étant **caractérisé en ce qu'**il comprend :

- l'élément de stripping (2) selon l'une quelconque des revendications 1 à 4 ;
- des moyens de support (40, 41) adaptés pour maintenir ledit élément de stripping (2) à la périphérie dudit cyclotron.

6. Ensemble de stripping (1) selon la revendication 5 comprenant des moyens d'ajustement capables d'ajuster la position dudit élément de stripping (2) dans le cyclotron de manière à augmenter l'efficacité d'extraction dudit élément de stripping (2) lorsque ledit faisceau de particules négativement chargées (1000) est soumis à arrachement par ladite deuxième feuille de stripping (20).

7. Ensemble de stripping (1) selon la revendication 5 ou la revendication 6 dans lequel lesdits moyens de support (41) sont adaptés pour soutenir ledit premier (2) et un deuxième élément de stripping (3) du même type que le premier élément de stripping (2), le deuxième élément de stripping (3) ayant une troisième feuille de stripping (11) et une quatrième feuille de stripping (21).

8. Ensemble de stripping (1) selon la revendication 7 comprenant des moyens d'entraînement adaptés pour déplacer lesdits moyens de support (41) d'une première position dans laquelle ledit faisceau de particules négativement chargées (1000) est soumis à arrachement par ladite première feuille de stripping (10) ou ladite deuxième feuille de stripping (20) dudit premier élément de stripping (2), à une deuxième position consécutive dans laquelle ledit faisceau de particules négativement chargées (1000) est soumis à arrachement par ladite troisième feuille de stripping (11) ou ladite quatrième feuille de stripping (21) dudit deuxième élément de stripping (3).

9. Ensemble de stripping (1) selon la revendication 7 ou 8 dans lequel lesdits moyens de support (41) sont une tête de stripping rotative, pouvant tourner autour d'un axe vertical, perpendiculaire à la trajectoire du faisceau de particules.

10. Procédé de stripping d'électrons d'un faisceau de particules négativement chargées (1000) à la périphérie d'un cyclotron pour extraire un faisceau de particules dudit cyclotron, ledit procédé étant **caractérisé en ce qu'**il comprend les étapes suivantes consistant à :

• fournir l'élément de stripping (2) de l'une quelconque des revendications 1 à 4 à la périphérie dudit cyclotron ;
• extraire ledit faisceau de particules au moyen de la première feuille de stripping (10) ;
• sans arrêter ledit cyclotron, dans le cas où ladite première feuille de stripping (10) est endommagée, extraire ledit faisceau de particules au moyen de ladite deuxième feuille de stripping (20).

11. Procédé selon la revendication 10 dans lequel ladite étape d'extraction dudit faisceau de particules au moyen de la deuxième feuille de stripping (20) comprend en outre l'étape consistant à :

• ajuster au moyen de moyens d'ajustement le positionnement dudit élément de stripping (2) à l'intérieur dudit cyclotron de manière à augmenter l'efficacité d'extraction de ladite deuxième feuille de stripping (20).

12. Procédé selon la revendication 10 ou la revendication 11 comprenant en outre les étapes consistant à :

• fournir un deuxième élément de stripping (3) du même type que ledit premier élément de stripping (2), ayant une troisième feuille de stripping (11) et une quatrième feuille de stripping (21) ;
• fournir des moyens de support (41) pour soutenir ledit deuxième élément de stripping (3) et ledit premier élément de stripping (2) ;
• vérifier si ladite première feuille de stripping (10) ou ladite deuxième feuille de stripping (20) dudit élément de stripping (2) est endommagée ;
• lorsque ladite vérification met en évidence des dommages, déplacer lesdits moyens de support (41) de telle manière que ledit faisceau de particules négativement chargées (1000) soit soumis à arrachement par ladite troisième feuille de stripping (11) ou ladite quatrième feuille de stripping (21) dudit deuxième élément de stripping (3).

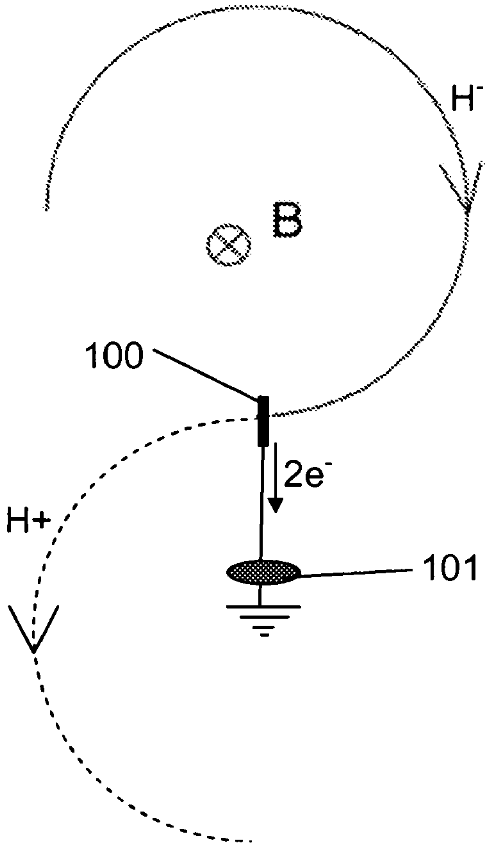

Fig. 1

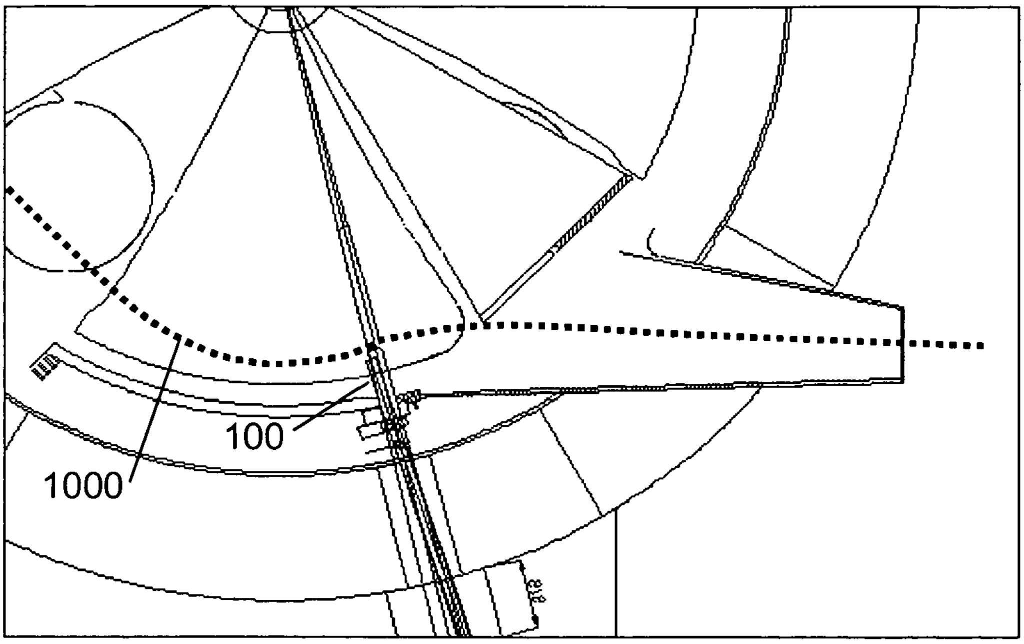

Fig. 2

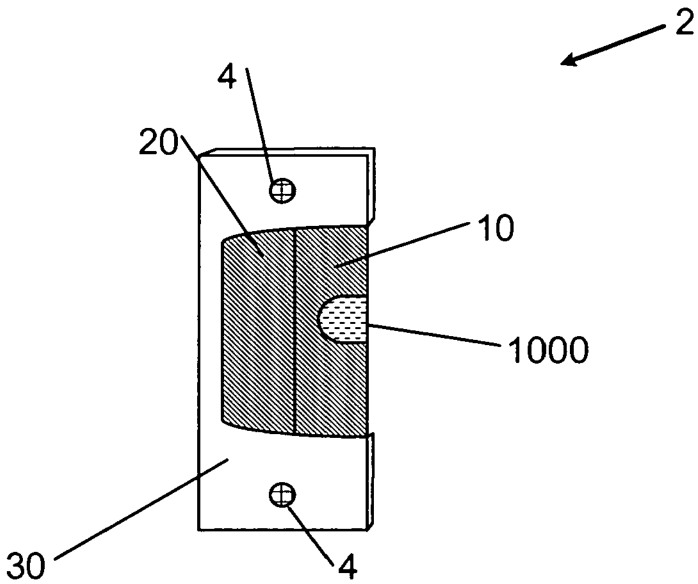

Fig. 3

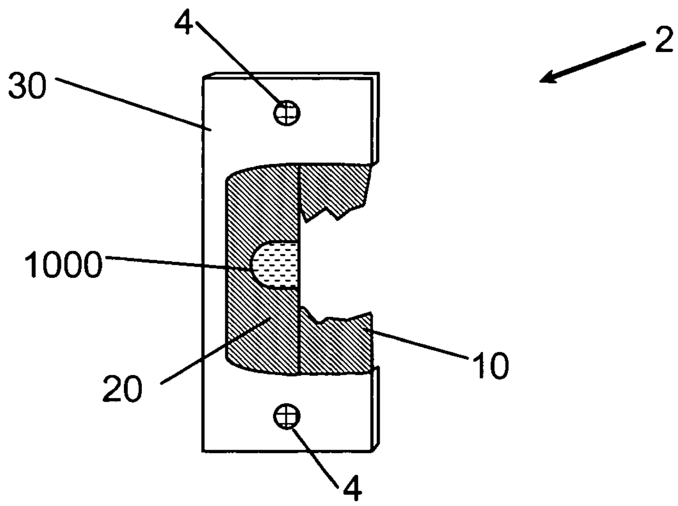

Fig. 4

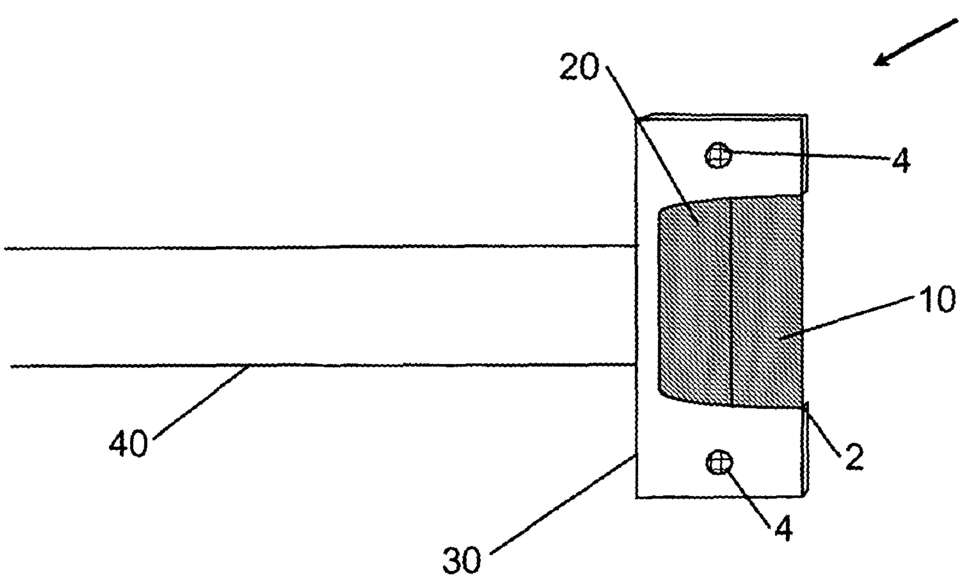

Fig. 5

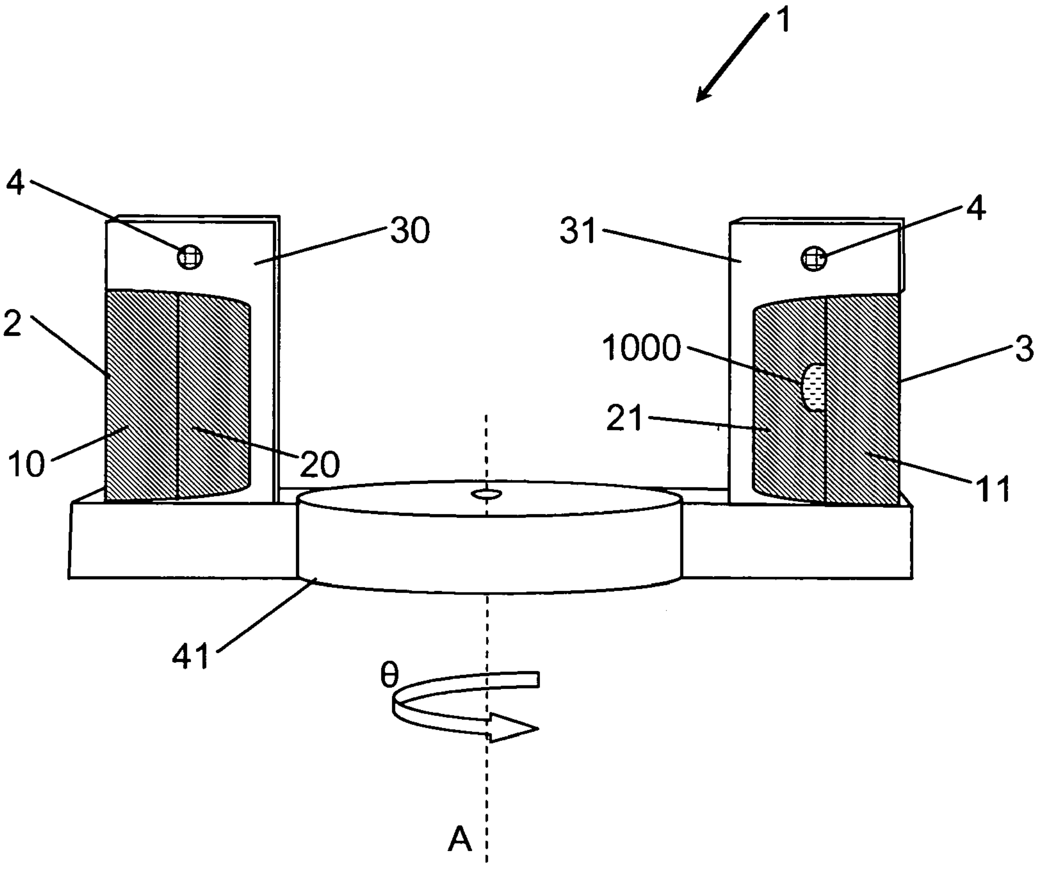

Fig. 6

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

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